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COVER DESIGN FOR A FLY ASH LANDFILL MOUND: A CASE ILLUSTRATION

Report No 90-273-K

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ABSTRACT

Two computer codes have been selected for the design of a cover system for a fly ash landfill mound. The first program is a two-dimensional finite-element code, which is used to compute the allowable surface infiltration into a fly ash mound. The second computer code HELP (Hydrological Evaluation of Landfill Performance) is used to optimize a multi-layer cover system design. To illustrate the use of these two computer codes, a cover design was proposed for the Nanticoke TGS long-term fly ash mound. This report describes the design procedure and presents results of the computer simulations.

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COVER DESIGN FOR A FLY ASH LANDFILL MOUND: A CASE ILLUSTRATION

1.0 INTRODUCTION

At present, Ontario Hydro's five coal-fired generating stations produce about one million tonnes of coal fly ash of which about 20-25% is utilized as a by-product material. The remaining material is commonly placed as landfill mounds on station properties at the Nanticoke TGS, Lambton TGS and Thunder Bay TGS. At the Lakeview TGS and the Atikokan TGS, suitable sites have been used or are being used for "off-site" disposal. In the late 1990s or early 2000s, these fly ash landfill mounds will have to be covered up and sealed in an environmentally acceptable manner. This undertaking will be very costly and the expenditure depends, to a large extent, on the design of the final cover system and the construction materials of the cover layers.

With the financial support of the Fossil Projects Planning Section of the Generation Planning and Approvals Program Department, the Civil Research staff initiated in late 1989 a study related to the design and construction of final covers on fly ash landfill mounds. Initially, a literature study was performed to gather information on cover design and other relevant topics. A report on this study was recently published/1/. Pursuant to the literature study, a search was undertaken to obtain suitable computer codes for cover design. As a result, two computer codes were selected which were used to perform the tasks required for the design optimization of a cover system. To explain and illustrate the important design

steps and procedure, these computer codes were used to design a tentative cover system for the fly ash landfill mound at the Nanticoke TGS. In this report, pertinent information about the use of these two computer codes and the main design steps are discussed.

2.0 NANTICOKE FLY ASH DISPOSAL SITE AND LANDFILL MOUND

Presently, about 600,000 tonnes of fly ash is produced annually at Ontario Hydro's 4,000 MW Nanticoke coal-fired generating station. The ash produced by the station from the early 1970s to 1981 was sluiced to a nearby 76-hectare lagoon (Figure 1). In 1981, a new operating system was adopted at the site in order to increase the storage capacity of the lagoon. In this system, as shown in Figure 2, the fly ash transport was routed through a primary settling cell, a secondary settling cell, then through the primary and secondary lagoons before the effluent exists from the site. Most of the ash particles settle out in the primary cells, which are constantly cleaned out by draglines. The dredged ash is hauled to the designated long-term storage area within the original lagoon clay dyke where it is stacked to form a storage mound.

Figure 3 is a main cross-section through of the fly ash mound showing various layers of ash and soils. The long-term stability of this ash mound section was evaluated for different assumed water table positions within the ash mound/2/. The water table positions are significantly influenced by the amount of surface infiltration through a final cover which would be constructed at the closure stage of the ash mound.

3.0 COMPUTER CODE FOR CALCULATING THE WATER TABLE POSITION WITHIN A FLY ASH MOUND

The first step in designing a cover system for a fly ash mound is the determination of the acceptable amount of surface infiltration percolating into the ash material. The amount of water infiltration is governed mainly by the hydraulic conductivity of the cover material, and the water infiltration percolates through the cover by gravity flow with a vertical

hydraulic gradient of unity. Thus the maximum rate of percolation is equal to the hydraulic conductivity of the cover. By providing a properly designed cover, the amount of infiltration into the mound can be minimized and the long-term water level and the generation of ash leachate within the mound can be controlled.

At the steady-state condition, the groundwater pressure distribution within a two-dimensional flow domain is governed by the Laplace's equation.

$$\frac{\partial^2 h}{\partial x^2}+\frac{\partial^2 h}{\partial y^2}=0 \qquad (1)$$

where h is the total hydraulic head.

This differential equation mathematically describes the energy loss through a soil medium. The assumptions that the derivation of this equation is based on are: 1) the soil is saturated, 2) the water and the soil are incompressible, and 3) the flow is laminar. The solution of the equation is a function of h(x,y) that describes the value of the hydraulic head h at any point in the flow domain.

Equation (1) can be solved by different approaches such as with an analytical technique, a physical modelling technique, an electrical analog modelling technique, or a numerical technique. Unfortunately, equation (1) can be integrated mathematically only for a few cases with simple flow domain geometry and boundary conditions. Under unconfined seepage flow conditions, in which the total hydraulic head along the phreatic surface is equal to the elevation of the phreatic surface, the development of an analytical solution for equation (1) is extremely difficult. With both physical and electrical modelling techniques, it is difficult to simulate the rate of infiltration at the recharge boundary.

Several existing two-dimensional computer codes were initially evaluated and finally an axisymmetrical finite-element computer code "PSI"/3/, developed by Civil Research staff, was selected for determining the effect of different covers on the groundwater build up within the ash mound at Nanticoke TGS.

A head-prescribed boundary condition was imposed at the discharge boundary, a-a' (the till layer underneath the natural clay layer), shown in Figure 3. For Case 1, the bedrock layer was assumed to be very permeable and no excess water pressure was built up within this zone. At this discharge boundary, a constant hydraulic head boundary condition equal to the elevation head of the bedrock layer was imposed. For Case 2, the till layer was assumed to be less permeable. An excess water pressure equal to the thickness of the natural clay layer was added to the elevation head at this boundary.

With the aid of the finite-element computer code PSI and the above-described boundary conditions, the relationship between the maximum groundwater level within the ash mound and the per cent precipitation infiltrating into the ash was established and plotted in Figure 4.

Based on the results shown in Figure 4, and on the relationship between the water level within the mound and the safety factor for slope stability of the mound presented in Table I, the allowable rate of water percolation through the cover should be limited to 10% of the total precipitation (the average annual precipitation on this area is equal to 980 mm) to ensure that the ash storage mound will have a long-term safety factor of 1.3.

The allowable rate of surface water infiltration through the cover into the ash mound also affects the amount of ash leachate generation. The amount of ash leachate entering the groundwater system beneath the ash mound can impact on the groundwater quality. Therefore, this environmental (ie groundwater quality) effect should also be considered in the determination of the allowable rate of surface water infiltration through the cover.

At the Nanticoke site, the impact of the fly ash storage mound on local groundwater is being monitored by a system of piezometers. This system consists of 4 nests of piezometers strategically located within and around the fly ash storage facility. It is anticipated that regular sampling and testing of the local groundwater will provide valuable data to help establish the environmental requirement for the final cover.

4.0 COVER DESIGN WITH THE HELP MODEL

Once the allowable amount of water infiltration into the fly ash mound is calculated as discussed in Section 3, a cover system can then be designed with the computer code, HELP (Hydrological Evaluation of Landfill Performance)/4/. The HELP computer model simulates the effects of hydrologic processes on the water balance for landfills by performing daily sequential analysis using a quasi-two-dimensional, deterministic approach. The dominant hydrologic considerations include precipitation of any form, surface storage, interception, surface evaporation, runoff, snowmelt, infiltration, vegetation, rooting depth, plant transpiration, soil evaporation, soil moisture storage, soil moisture potential, unsaturated flow, and vertical and lateral saturated flow. The program handles each of these considerations, often in a simplifed manner, to estimate runoff, evapotranspiration, vertical drainage to liners, percolation through liners, and lateral drainage from layers above liners.

4.1 The HELP Model

The first step in performing a simulation with the HELP model is to determine the environmental characteristics of the site in question. These characteristics include daily values for precipitation, temperature, solar radiation and growing season. If these data are not available, the HELP model includes a default database containing values that describe climatic conditions for 102 US cities. This default database contains historical data for a 5-year period (1974-78). Version 2.02 of the HELP model also incorporates a synthetic weather generator which statistically generates values for daily precipitation, temperature

and solar radiation from distribution coefficients representing 139 cities. Mean monthly precipitation and temperature values for the site in question may be used as input to the synthetic weather generator to improve the daily climatological data.

For the HELP simulations performed in this study, mean monthly precipitation and temperature values for the Nanticoke area (Port Dover) were used as input to the synthetic weather generator and statistical coefficients for Buffalo, NY were specified. One advantage of using the synthetic weather generator is that up to 20 years of data may be produced. In this study, only 10-year simulations were performed.

Following input of climatological data, a landfill profile is specified and appropriate soil conditions are chosen. The HELP model allows for four different layer types: 1) a vertical percolation layer, 2) a lateral drainage layer, 3) a barrier soil layer and 4) a barrier soil layer with synthetic liner. Simplistic models (generally one-dimensional) are used to simulate water movement within each layer type. Although certain conventions must be followed in specifying a particular landfill profile (eg a vertical percolation layer must not be placed below a lateral drainage layer), up to 12 layers and 4 liners may be input to the profile. The following design parameters must also be considered: 1) layer thickness must be greater than zero, 2) slopes of lateral drainage layers may vary from 0 to 30%, 3) lateral drainage path lengths may be up to 2000 ft (610 m), 4) landfill surface area must be specified and 5) liner leakage fractions may vary from 0 to 1.

The landfill profile chosen for simulation in this study consisted of three major components: 1) a proposed 4.5 ft (1.4 m) thick cover system consisting of two vertical percolation layers (slag cover over stabilized fly ash), a drainage layer (gravel) and a barrier liner (clay or bentonite/fly ash mix); 2) a fly ash landfill consisting of a 70 ft (21 m) thick vertical percolation layer; 3) a 30 ft (9.1 m) thick barrier layer of clay overburden.

The clay overburden at the Nanticoke site is underlain by fractured limestone which is hydraulically connected to Lake Erie. The cover system modelled in this study is shown schematically in Figure 5.

Following specification of the landfill profile, the user must select appropriate soil parameters for each specified layer. The HELP model provides a database of 18 different soil types with default soil characteristics such as porosity, field capacity, wilting point and saturated hydraulic conductivity. This database of soil characteristics and associated soil textural classes has been developed largely from agriculture soils and may not be entirely appropriate for certain engineering soil types. The selection of default soil types for modelling purposes should be based on their associated parameters and not on their textural classes. The user also has the option of manually inputting soil characteristics from his/her own database. The HELP model will use the input soil parameters to calculate values of unsaturated hydraulic conductivity and capillary pressure which are required when modelling moisture flow in unsaturated media. The soil parameters chosen for the landfill profile in this study are shown in Table II. The initial soil moisture contents were initialized by the program by equating them to field capacity for percolation and lateral drainage layers and to porosity for barrier layers.

The rainfall-runoff process modelled in the HELP program is based on the SCS (Soil Conservation Service) curve-number method/5/. This procedure, developed from rainfall-runoff data for large storms on small watersheds, has shown little evidence of being sensitive to slopes less than 20%. Therefore, surface slopes are not considered in the HELP model. The curve-number method is entirely dependent on surface soil type and on the quality of vegetative cover. For slopes greater than 20%, the curve number can always be modified by the user to account for slope effects. In the present investigation, a surface layer of coarse sand with no vegetative cover was used. This approach was considered conservative as it would permit maximum infiltration into the cover system and minimize evapotranspiration.

4.2 Results of Parametric Analysis

The HELP model was used to determine the amount of infiltration which would enter the fly ash landfill from the specified cover system. The critical component of the cover system is the drainage layer which acts to divert any infiltration away from the ash. The surface layer of slag only serves to minimize dusting problems and the 1 m thick layer of stabilized fly ash only serves to protect the internal drainage system from frost damage and desiccation. The parameters which affect the performance of the drainage layer are its hydraulic conductivity, its slope angle and drainage length. These three parameters control the flow capacity of the drainage layer itself. In addition, the hydraulic conductivity of the underlying barrier layer is also critical as it must limit percolation into the ash and allow enough hydraulic head to build up within the lateral drainage layer. The magnitude of hydraulic head should be optimized to induce flow within the lateral drain, but not to induce excessive percolation through the barrier layer.

The results of the parametric study on the critical parameters of the internal drainage system are summarized in Figures 6 and 7. The amount of infiltration into the ash is plotted as a percentage of precipitation. The percentages plotted are average annual totals for the 10-year simulation period. Average annual precipitation is approximately equal to 100 cm.

Because of the surface layer characteristics and climatological conditions input to the HELP simulations, runoff averaged 10% and evapotranspiration averaged 55% of annual precipitation for the 10-year simulation period. The remaining moisture infiltrated into the cover system and was partitioned between lateral drainage flow and percolation.

Figure 6 is a plot of infiltration versus drainage length for three different slope angles. The hydraulic conductivities of the drain and barrier are 10^{-3} and 10^{-9} m/s respectively. As the drain slope angle decreases from 3 to 1%, the amount of infiltration into the ash increases because more moisture is available to percolate through the barrier layer. As the drainage

length increases, the driving gradient decreases, which again allows more moisture to build up and percolate through the barrier layer.

Figure 7 is a plot of infiltration into the ash versus drainage length for various combinations of drain/barrier hydraulic conductivities. The slope of the internal drain was arbitrarily fixed at 3% during these simulations. From this plot, it can be determined that the hydraulic conductivity of the barrier layer has a greater influence on infiltration than the conductivity of the drainage layer. A one order-of-magnitude increase in the barrier's hydraulic conductivity results in a 4-fold increase in infiltration. Increasing drainage length only leads to significant increases in infiltration when the hydraulic conductivity of the drain equals 10^{-4} m/s.

Based on the HELP model simulations, a cover system including an internal drain and barrier will limit infiltration to 10% of precipitation (10 mm/a) under the following conditions: 1) drainage layer slope = 3%, 2) drainage layer hydraulic conductivity = 1×10^{-3} m/s, 3) barrier layer hydraulic conductivity = 1×10^{-9} m/s. Infiltration appears independent of drainage length under the above conditions. If the hydraulic conductivity of the drainage layer decreases to 1×10^{-4} m/s, drainage length must be limited to 40 m to maintain the 10% criterion. Drainage length in these simulations represents the horizontal distance between the crest and the toe of the drain. The HELP model simulations also revealed that the thickness of individual layers within the cover system does not influence the magnitude of infiltration into the ash, but, rather the amount of time before the system reaches a steady state. The design thickness of each layer should be selected, taking into consideration construction and material variability, so as to ensure that the critical soil parameters remain unchanged throughout the life of the cover.

5.0 SUMMARY

To outline the design procedure of a final cover for a fly ash landfill mound, a tentative cover design was done for the fly ash mound at the Nanticoke TGS lagoon site. A finite-element two-dimensional computer code, developed by the staff of the Civil Research Department, was used to determine first the equilibrium position of the water table within the landfill mound for several assumed surface infiltration rates. The allowable infiltration was then estimated on the basis of an acceptable safety factor for the stability of the mound, which depends on the water table position. After the allowable infiltration through a cover was established, a second computer code HELP (Hydrological Evaluation of Landfill Performance) was used to optimize a multi-layer cover system design, which usually consists of a surface layer for dust and erosion control, a frost protection layer, an internal drainage layer and a hydraulic barrier layer.

As a continuation of the research effort on landfill covers, a testing facility (ie three small-scale fly ash mounds 3 meters high) has been constructed at the Nanticoke fly ash site to achieve the following research goals:

1. To study the hydraulic behaviour of different cover systems.

2. To establish a suitable analytical technique to predict the long-term performance of final covers.

3. To investigate the hydraulic characteristics of unsaturated fly ash.

4. To assess and develop measuring devices for the monitoring of the conditions within the fly ash test mounds.

5. To study leachate generation and migration in a fly ash mound.

6. To study in the laboratory, the hydraulic characteristics of compacted fly ash modified by additives and the potential use of this modified ash as a construction material for the hydraulic barrier layer in a final cover system.

This research project is on-going and the experimental data to be collected will be useful in designing a cost-effective final cover system for all of Ontario Hydro's fly ash landfill mounds.

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2. K.C. Lau and H.T. Chan (1989). "Geotechnical Considerations for the Design of the Extended Fly Ash Mound at Nanticoke TGS". Ontario Hydro Research Division Report No 89-229-K. September 1989.

3. K.C. Lau and H.T. Chan (1989). "The Study of a Water Table Within a Fly Ash Mound at Nanticoke". Ontario Hydro Research Division Report No 89-39-K. March 1989.

4. Schroeder, P.R., Gibson, A.C. and Smolen, M.D., (1984). The Hydrologic Evaluation of Landfill Performance (HELP) Model: Volume II. Documentation for Version 1. EPA/530-SW-84-010, US Environmental Protection Agency, Cincinnati, Ohio, 256 pp.

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TABLE I

Relationship Between the Maximum Groundwater Level Within the Ash Mound and the Safety of the Ash Mound

	Assumed Friction Angle of the Clay			
Maximum groundwater level	15°*	20°	25°	
203.29 m (667')	1.00	1.20	1.29	
197.19 m (647')	1.07	1.27	1.35	safety factors
189.27 m (621')	1.15	1.35	1.43	

*the residual frictional angle of the weathered clay

TABLE II

Soil Parameters of Landfill Profile Input to HELP Model

LAYER NO	THICKNESS (m)	POROSITY (VOL/VOL)	FIELD CAPACITY (VOL/VOL)	WILTING POINT (VOL/VOL)	INITIAL MOISTURE CONTENT (VOL/VOL)	SATURATED HYDRAULIC CONDUCTIVITY (m/S)
1	0.15	0.417	0.045	0.020	0.045	1×10^{-4}
2	1.0	0.475	0.377	0.264	0.377	2×10^{-7}
3	0.15	0.417	0.045	0.020	0.045	1×10^{-3}
4	0.15	0.430	0.366	0.280	0.430	1×10^{-9}
5	21.0	0.464	0.310	0.188	0.310	6×10^{-7}
6	9.1	0.430	0.366	0.280	0.430	1×10^{-9}

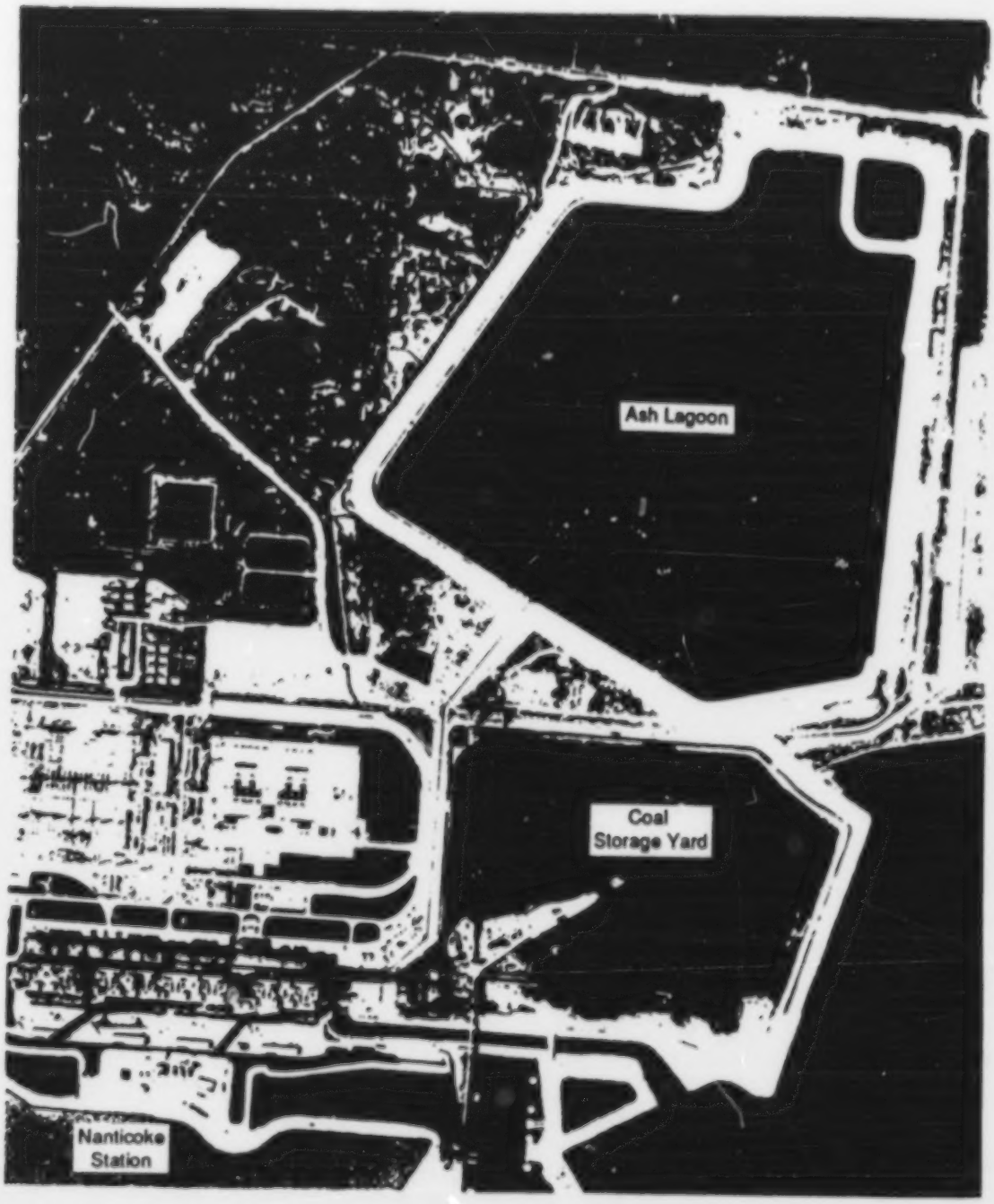

FIGURE 1

AIRPHOTO OF NANTICOKE STATION AND THE ASH LAGOON (1978)

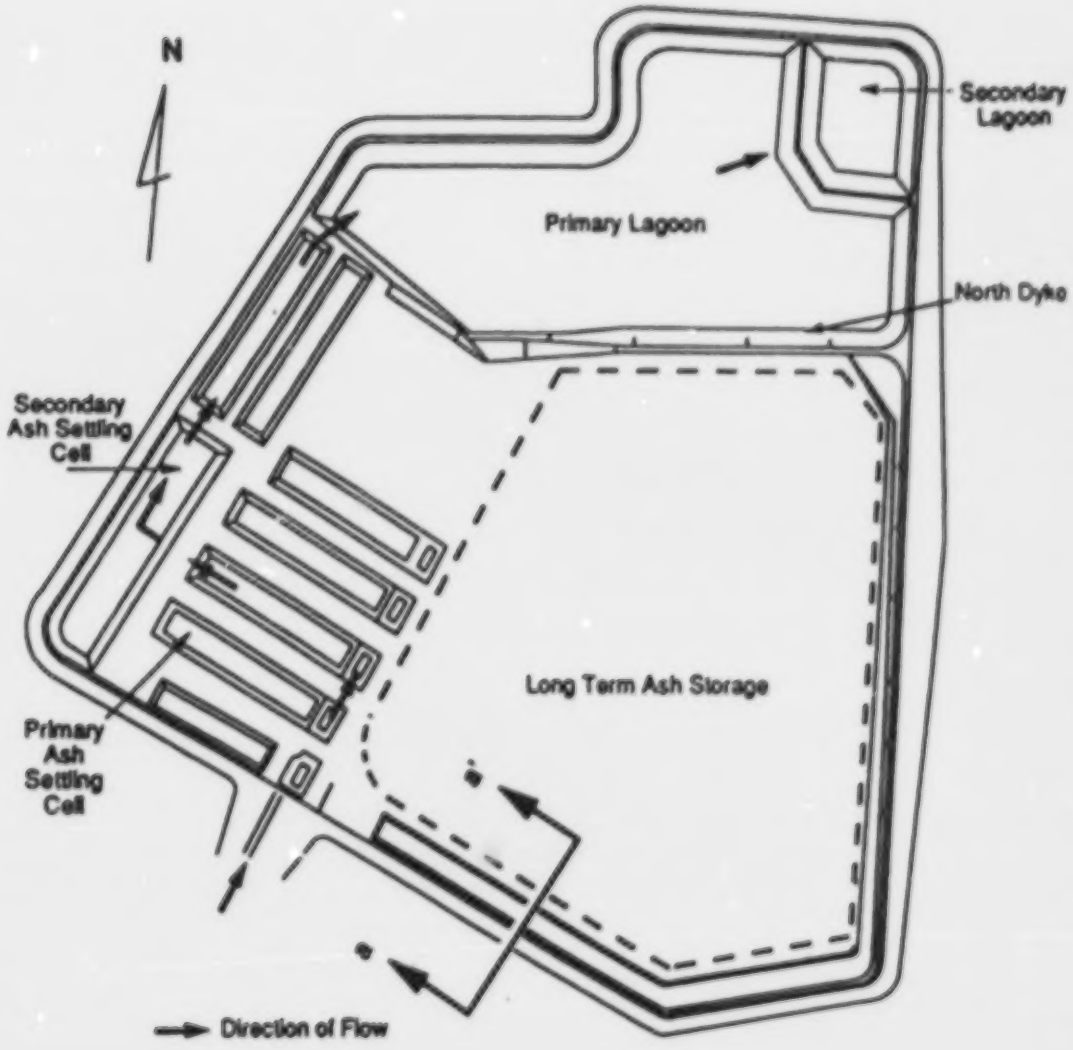

FIGURE 2

PLAN VIEW OF THE EXISTING ASH STORAGE SITE

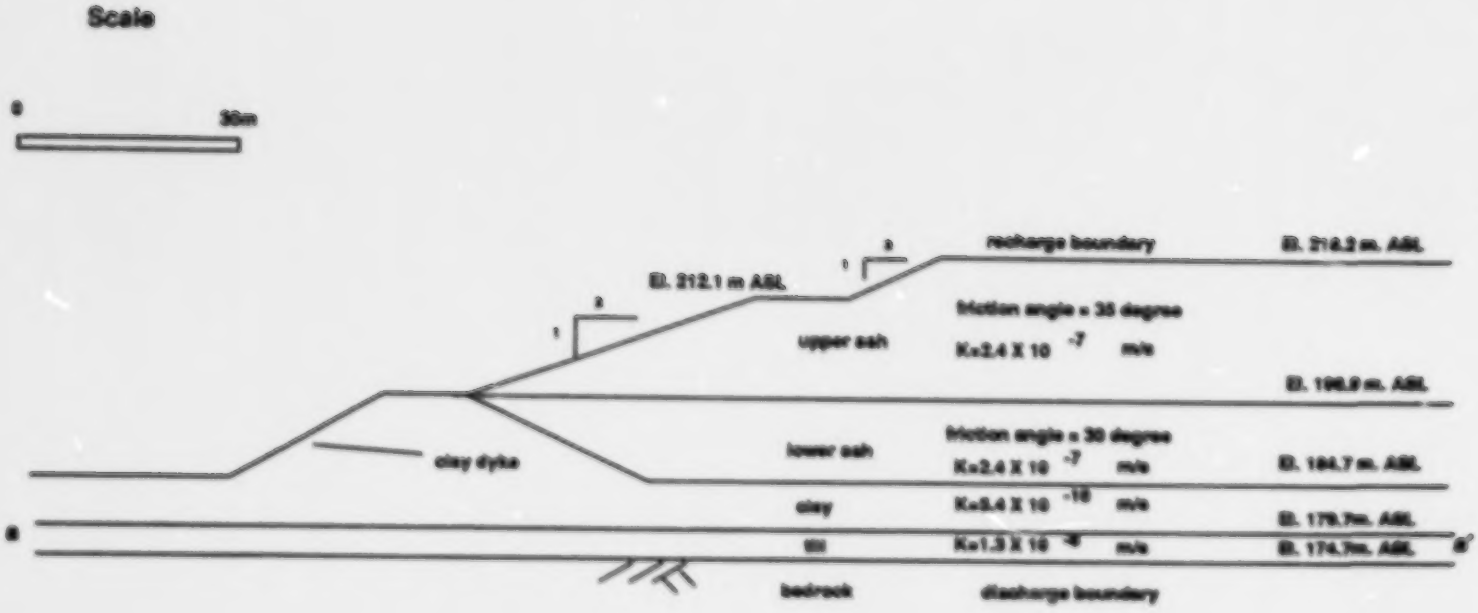

FIGURE 3

CROSS-SECTION a-a' OF THE ASH STORAGE MOUND

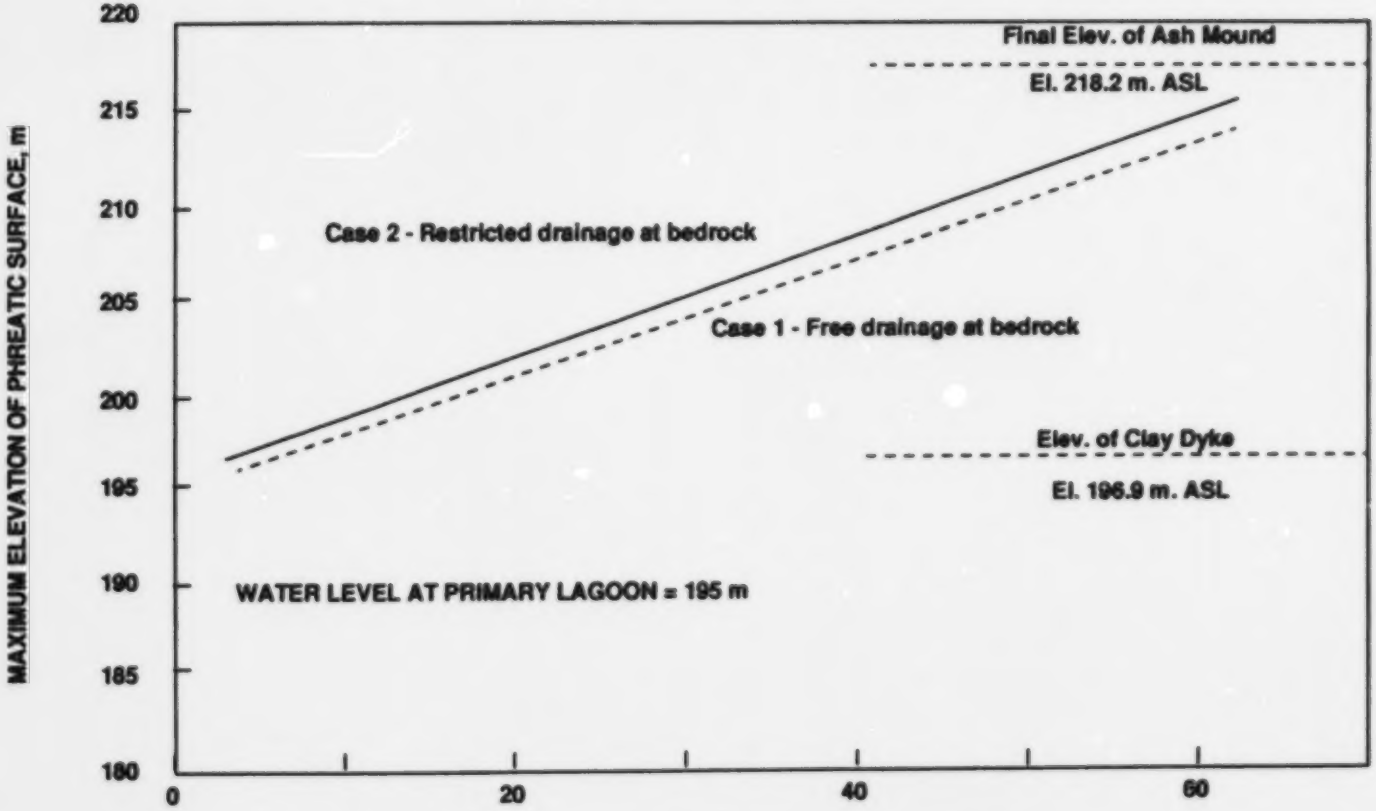

FIGURE 4

RELATIONSHIP BETWEEN THE MAXIMUM ELEVATION OF PHREATIC SURFACE AND PERCENT PRECIPITATION INFILTRATING INTO THE ASH - NANTICOKE TGS ASH MOUND.

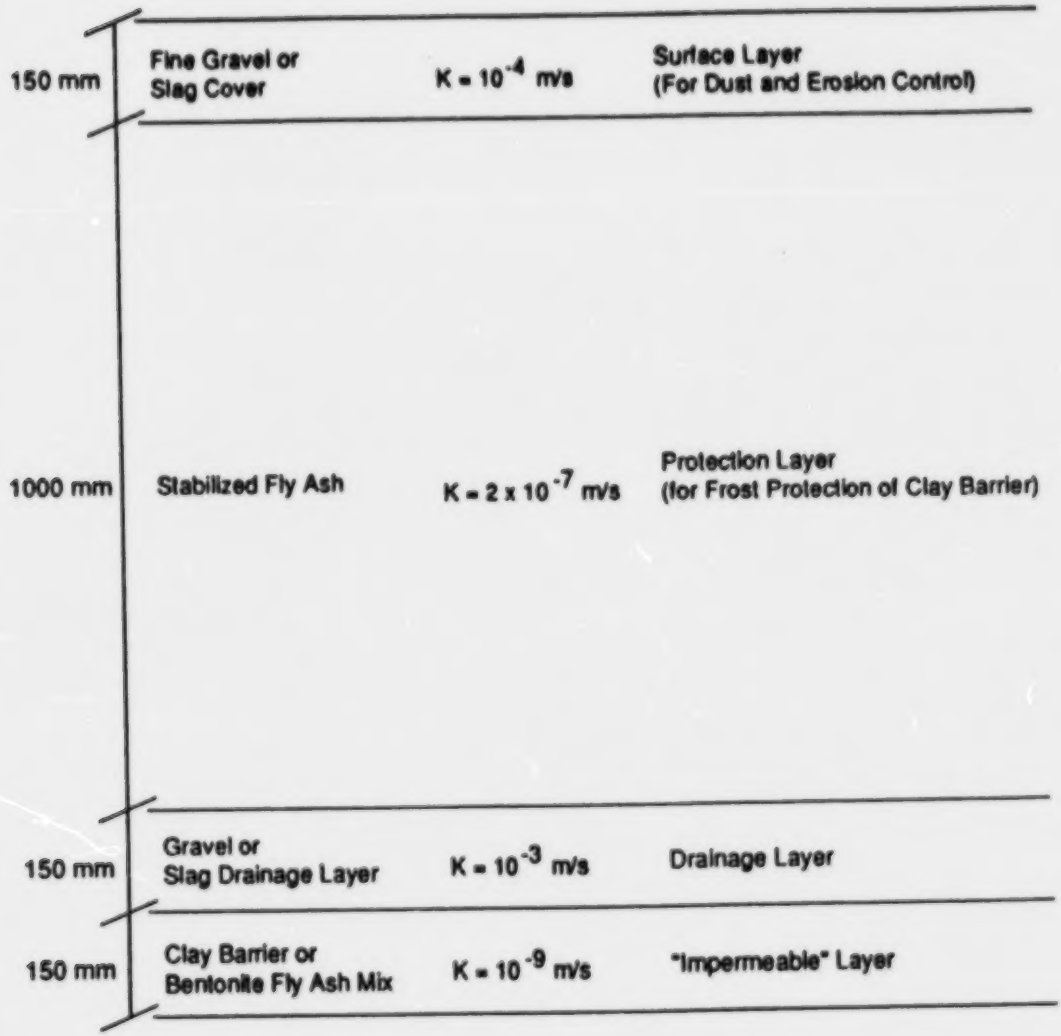

FIGURE 5

PROPOSED FLY ASH COVER

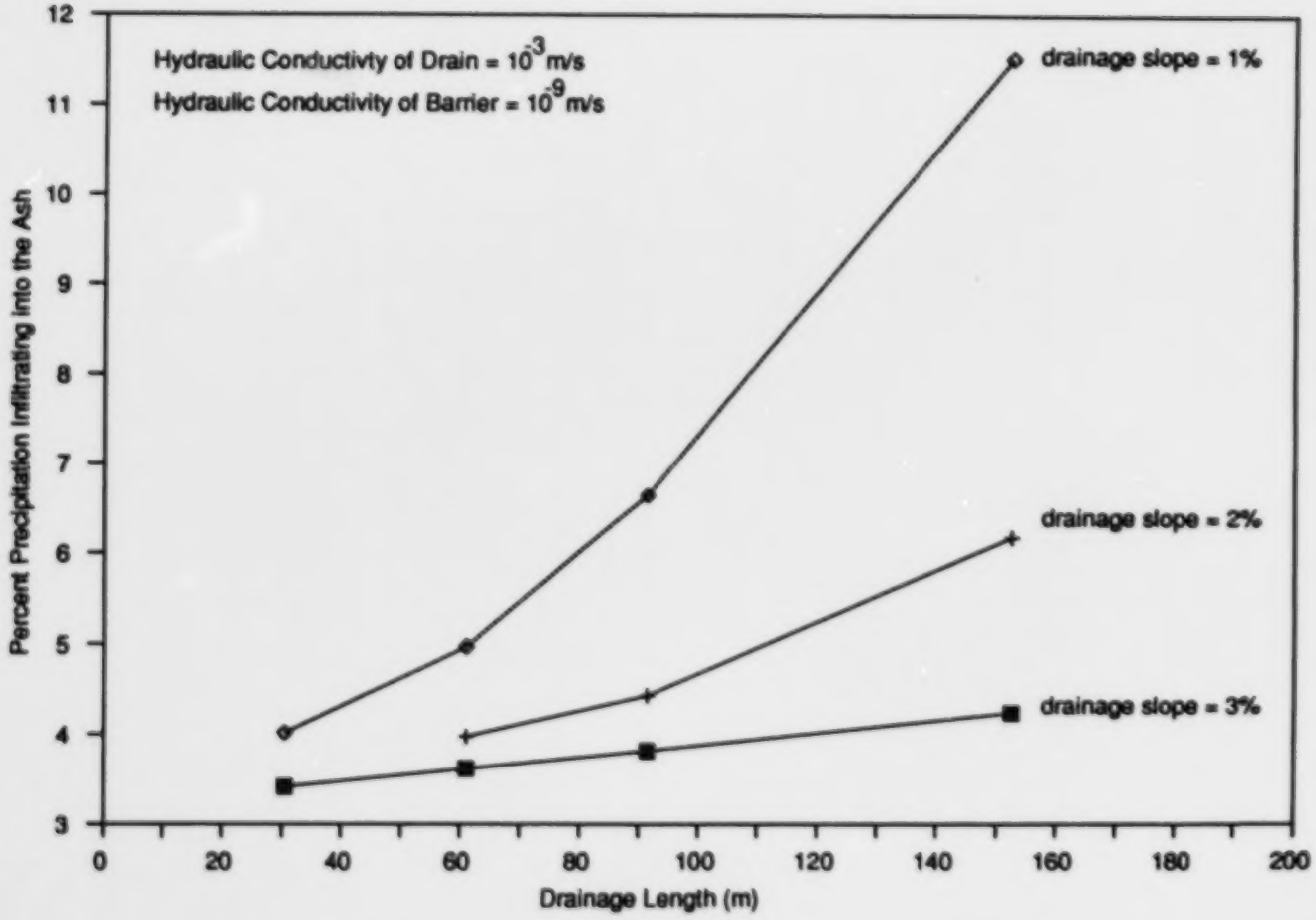

FIGURE 6

HELP MODEL RESULTS - NANTICOKE FLY ASH COVER

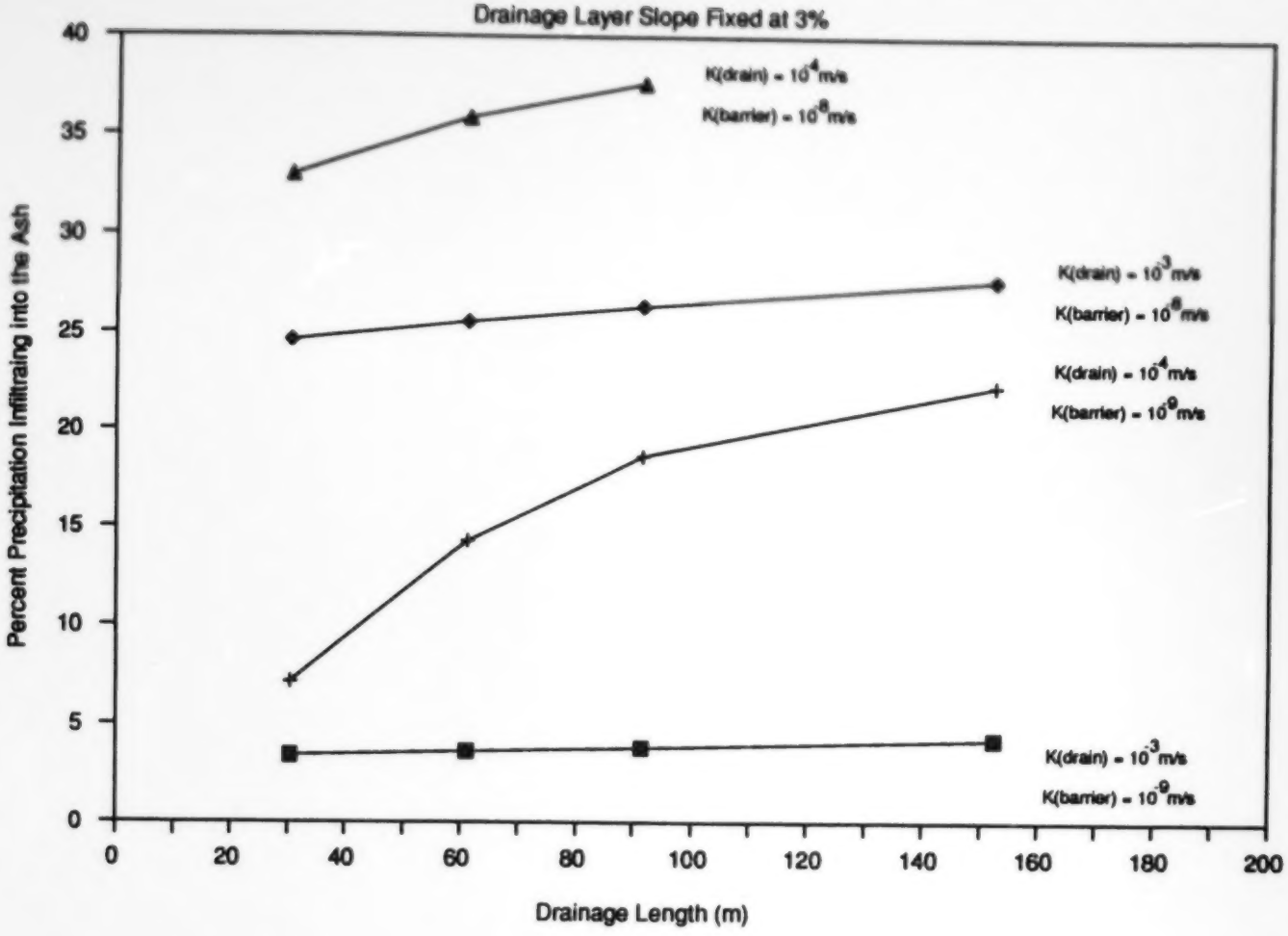

FIGURE 7

HELP MODEL RESULTS - NANTICOKE FLY ASH COVER